THE RECONSTRUCTION OF A MIDDLE PROTEROZOIC OROGENIC BELT IN NORTH–CENTRAL NEW MEXICO, U.S.A.

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Abstract—Correlation of Proterozoic rocks and structures in the Tusas, Picuris, Truchas and Rio Mora uplifts in northern New Mexico shows ~50 km of post–Precambrian, probably Laramide, right–lateral strike slip across a zone of north–trending faults. Similar peak metamorphic P–T conditions and P–T paths from each uplift suggest that the intersection of subhorizontal isobars with steeply dipping structures can be used as piercing lines to constrain the magnitude of slip. Based on the restoration of Laramide slip, a fundamental crustal boundary separating older, 1700 Ma rocks (Yavapai crustal province) from younger, ~1650 Ma supracrustal rocks (Mazatzal crustal province) is proposed. As the dominant regional deformation appears to be related to the assembly of the younger crustal material to the continental margin at ~1650 Ma, north–central New Mexico is within the area affected by the Mazatzal orogen. In addition to the proposed crustal and orogenic province assignments, several distinctive structural, metamorphic and plutonic belts are recognized. From north to south these include (1) the Cimarron–Taos high–grade metamorphic area characterized by relatively high pressures (6–8 kbar) and abundant 1650 to 1700 Ma plutons; (2) the Ortega ductile thrust belt, a north–vergent, brittle–ductile fold and thrust belt that imbricates rocks of the Vadito and Hondo groups and contains few plutons; and (3) the Yavapai–Mazatzal transition zone, a structurally complex transition from older Yavapai crust to younger Mazatzal crust. This transition zone includes: (1) the Pecos thrust sheet, which places pre–1700 Ma volcanogenic basement that is thrust over the Ortega fold-and-thrust belt; (2) a large ~1650 Ma plutonic complex in the Santa Fe Mountains and southern Pecos river valley; and (3) ~1450 Ma granites in the Nacimiento, Sandia and Pedernal uplifts. The geometry of these belts suggests that heat from ~1650 Ma granitic plutons emplaced below the Ortega thrust sheet and thrust up over the complex (in the Pecos thrust sheet) is responsible for the regional metamorphism of the Ortega thrust belt.

INTRODUCTION

The discontinuous nature of exposed Proterozoic rock in New Mexico (Fig. 1) makes it difficult to delineate Proterozoic crustal and deformational province boundaries. Previous subdivisions have emphasized a terrane approach with terranes defined by differences in rock type, age, or metamorphic grade (Grambling et al., 1988; Condie, 1992). However, the restoration of Laramide strike–slip displacement as proposed by Karlstrom and Daniel (1993) provides new insight into the distribution of Proterozoic rocks in New Mexico. The primary goal of this paper is to provide a new working hypothesis for the geometry of Proterozoic crustal and orogenic provinces in New Mexico and discuss the significance of several distinct metamorphic, plutonic and deformational belts recognized from the reconstruction of Karlstrom and Daniel (1993). Towards this end, we review the realignment of the Tusas, Picuris, Truchas and Rio Mora uplifts in New Mexico, and the metamorphic P-T evolution of these uplifts (Daniel et al., 1991; 1992; Daniel, 1992; Williams and Daniel, 1994).

This paper follows the hypothesis that 1650 to 1600 Ma (Mazatzal orogeny) was the time of development of the main regional structures and metamorphism in New Mexico (Bowring and Karlstrom, 1990; Bauer and Williams, 1994). An alternate hypothesis (Grambling et al., 1989; Grambling and Dallmeyer, 1993) proposes that the regional metamorphism and deformation was contemporaneous with the emplacement of the 1450 to 1400 Ma granites. We recognize significant reactivation of old fabrics, new deformation, and contact metamorphism around ~1400 Ma plutons (Nyman et al., 1994); however, we believe that this 1400 Ma tectonic–thermal event did not fundamentally alter the orogenic structure created by the collisional assembly of the continental lithosphere between 1650 and 1600 Ma.

It is important to emphasize the distinction between orogens, i.e. *deformational* provinces, and *crustal* provinces. We follow Karlstom and Bowring (1993) by using the term Yavapai orogen to refer to that region of the Southwest where deformation is documented to be 1700 Ma or older; the Mazatzal orogen refers to that part of the Southwest where the major regional deformation is between 1650 and 1600 Ma. The terms Yavapai *crustal* province and Mazatzal *crustal* province are used to group together rocks of similar age. We place supracrustal rocks that are ~1700 Ma or older into the Yavapai crustal province, whereas supracrustal rocks that are ~1650 Ma or younger are placed into the Mazatzal crustal province. This nomenclature distinguishes between rocks that we interpret to be a part of the older continent or continental margin, and younger arc–related rocks that were accreted to the margin of this continent. Because deformation may be transmitted far inboard from the actual continental margin, the Mazatzal orogen incorporates rocks from both the Mazatzal and Yavapai *crustal* provinces. We hope that the extension of orogen and crustal province names from Arizona to New Mexico will create a consistent framework for understanding the Proterozoic evolution of the Southwest.

PROTEROZOIC LITHOSTRATIGRAPHY

As summarized by Bauer and Williams (1989), the oldest rocks in New Mexico are 1760 to 1720 Ma mafic metavolcanic sequences that include the Gold Hill complex of the Taos Range, the Moppin complex of the Tusas Mountains, and the Pecos complex of the Pecos river valley. These complexes contain amphibolite (with local pillow structures), mafic schists, calc–silicates, and banded iron formation all intruded by 1750 to 1720 Ma granodiorite plutons. These rocks were called the Taos and Pecos terranes by Grambling et al. (1988). Condie (1992) placed the Gold Hill and Moppin complexes into the Dubois terrane and the Pecos complex into the Pecos terrane. Mafic metaigneous rocks south of the El Oro dome (O'Neill, 1990) may be equivalent to the Pecos complex. Slightly older (~1780 Ma) supracrustal (Irving Formation) and granitic (Twilight Gneiss) rocks similar in character to the Moppin and Gold Hill complexes are exposed in the Needle Mountains of southern Colorado (Tewksbury, 1989). We consider all of these mafic metavolcanic complexes to represent a heterogeneous sequence of arc–related rocks that forms the crust of northern New Mexico.

Overlying this mafic metavolcanic "basement", is a felsic metavolcanic and metasedimentary "cover" sequence recognized in most of the uplifts in northern New Mexico. The oldest unit, the Vadito Group (1700 Ma), is dominated by felsic metavolcanic and metasedimentary rocks with distinctive felsic quartz–eye schists, metaconglomerates and minor amphibolites. A unique Mn^{3+}–rich layer (1 to 100 m thick) characterized by Mn^{3+}–andalusite, piemontite and other Mn^{3+}–rich minerals, is found at the top of the Vadito Group and is interpreted as a soil horizon or a hydrothermally altered stratigraphic layer (Grambling and Williams,

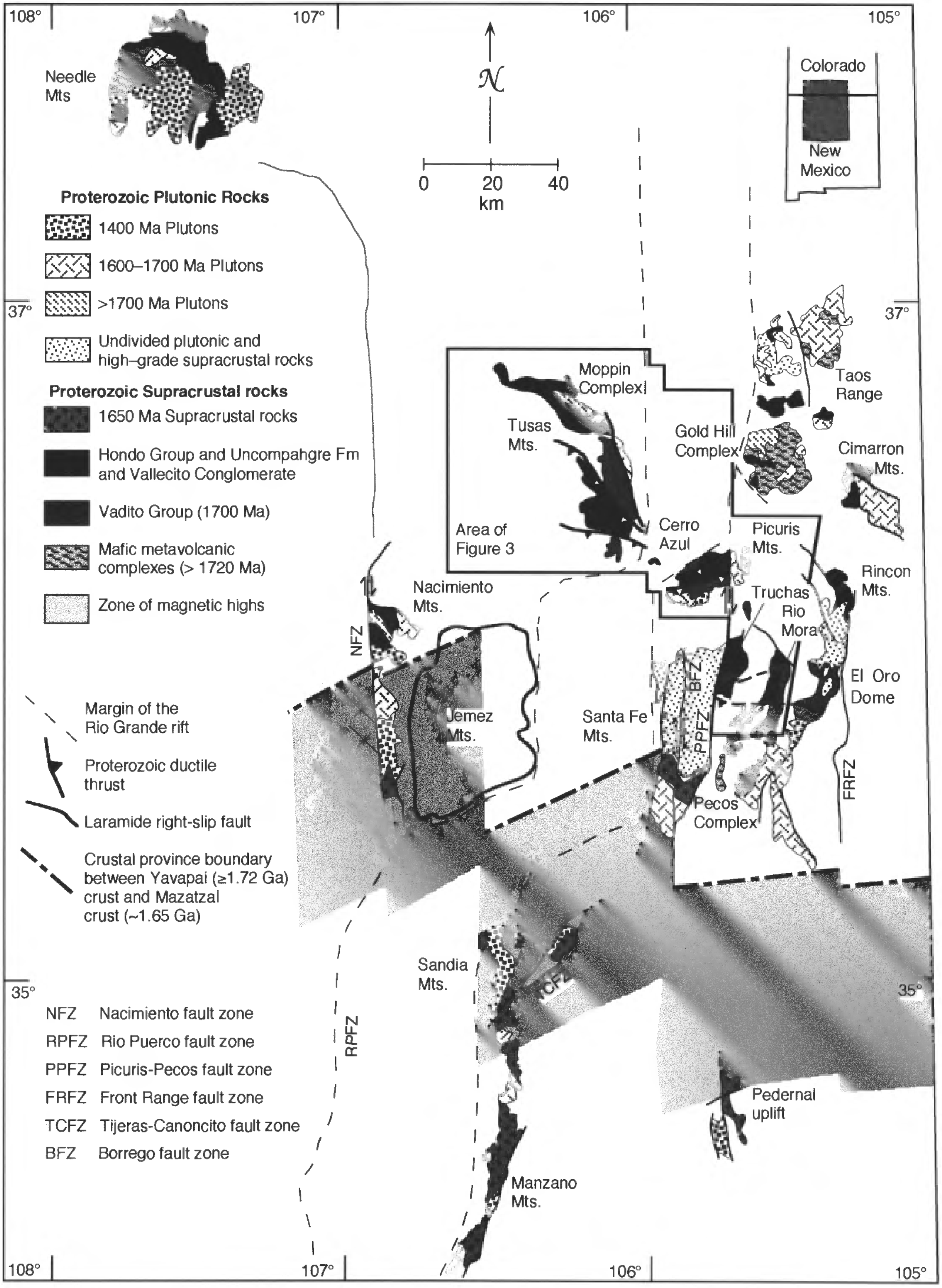

FIGURE 1. Current distribution of Precambrian rocks in north–central New Mexico. Proposed Yavapai–Mazatzal crustal province boundary is offset by Laramide, right–lateral strike–slip faults (modified from Karlstrom and Daniel, 1993).

1985).

The Hondo Group conformably overlies the Vadito Group and is dominated by the ~1 km thick, aluminous quartzite of the Ortega Formation, a shallow marine "shelf" sequence that was derived from the north (Soegaard and Erikson, 1986). A sequence of interlayered schists and quartzites called the Rinconada Formation, followed by schists and phyllites of the Pilar Formation and Piedra Lumbre Formation, overlie the Ortega Formation. The Uncompahgre Formation of the Needle Mountains is similar in thickness and lithology to the Ortega Formation, also contains Mn^{3+}–andalusite (Burns et al., 1980), and is probably stratigraphically equivalent with the Ortega Formation (Wobus. 1985; Karlstrom and Daniel, 1993). Together, the Vadito and Hondo groups were called the Truchas terrane by Grambling et al. (1988), whereas Condie (1992) placed them into the Manzano overlap sequence.

Available geochronologic evidence (Bauer and Pollock, 1993) suggests that the pre–1700 Ma, mafic metavolcanic "basement" and the ~1700 Ma Vadito and Hondo group "cover" sequence are missing in central and southern New Mexico, which is characterized instead by 1670–1640 Ma interlayered felsic and mafic metavolcanic schists, quartzites and minor pelitic schists. This younger sequence of rock is best documented in the southern Santa Fe Mountains (Fulp, 1982; Renshaw, 1984; Moench et al., 1988) and in the southern Manzano Mountains (Bauer, 1983; Thompson et al., 1991). Grambling et al. (1988) used the terms Santa Fe and Manzano terranes, respectively, for these rocks. Condie (1992) placed these supracrustal rocks together with the Vadito and Hondo groups into the Manzano overlap assemblage.

RECONSTRUCTION OF A MIDDLE PROTEROZOIC OROGENIC BELT

The discontinuous exposures of Proterozoic rocks in New Mexico are due in part to the opening of the Rio Grande rift and to the proposed Laramide right–slip faulting (Chapin and Cather, 1981; Chapin, 1983; Karlstrom and Daniel, 1993). To a first approximation, deformation associated with the opening of the Rio Grande rift is east–west extension. The proposed Laramide right–slip displacement was apparently accommodated across a broad network (approximately 175 km wide) of north–trending, high–angle faults spanning from the east margin of the Colorado Plateau to the range–bounding faults of the southern Sangre de Cristo Mountains (Fig. 2).

Karlstrom and Daniel (1993) proposed that the right-slip displacement across the central part of this zone is constrained by piercing lines defined in the Tusas, Picuris, and Truchas–Rio Mora uplifts. The coincidence of the subhorizontal isobaric surface (Grambling and others, 1989) with the present erosional level allows the map traces of steeply dipping stratigraphic markers, ductile thrusts and fold axial planes to be used as regional piercing lines. The subhorizontal nature of the basal Paleozoic unconformity in these uplifts shows that post–Mississippian displacement and tilting between ranges is minor. These piercing lines are discussed in more detail below as they are the best evidence to date for the geometry and scale of strike–slip displacement in New Mexico.

Large–scale structures and stratigraphic units can be correlated between the ranges (Fig. 3). These include the correlation of the Vadito and Hondo groups (especially the Mn–rich marker layer), and the alignment of a major overturned syncline (the Hondo syncline) and the major thrust faults (the Plomo and Pilar faults in the Picuris Mountains; Bauer, 1993) that bound this synform. The restoration (Fig. 3) shows approximately 37 km of right–lateral offset along the Picuris–Pecos fault as originally proposed by Miller et al. (1963). The model requires that another fault system (presumably buried by Rio Grande rift–related sediments) is present to accommodate the 15 km offset of Proterozoic units and structures between the Tusas and Picuris mountains (the hypothetical Tusas–Picuris fault zone of Karlstrom and Daniel, 1993). Within the rift at Cerro Azul, a small outcrop of the Mn–marker layer (Kepes, 1985) is interpreted to be bounded by splays of this proposed fault system. The realignment of these four uplifts also brings a zone of NE–trending magnetic anomalies (see Fig. 2) into alignment.

Proterozoic rocks in the Rincon–El Oro dome area represent a slightly deeper level of the fold–thrust belt seen in Rio Mora, and no major strike–slip faulting is recognized or proposed between these areas. The correlation with the Needle Mountains to the west is based upon the similarity in age, rock types and the basement (Irving–Twilight Fm) – cover (Uncompahgre Fm) relationship (Tewksbury, 1989) with the Early Proterozoic rocks in the Tusas uplift. Cuspate–lobate folding of basement and cover in the Needle Mountains (Harris et al., 1987) suggests the Needle Mountains may have been farther inboard or structurally higher than the imbricate thrusts and folds of the Tusas Mountains (Williams, 1991a). No piercing points have been documented between the Needle and Tusas Mountains, although Karlstrom and Daniel (1993) used the pattern of magnetic anomalies to suggest up to 100 km of right–lateral offset across a zone that includes both the Nacimiento fault zone and a hypothetical fault buried in the rift. Similarly, the realignment of magnetic anomalies across the Front Range fault zone suggests an additional 5–10 km of right slip, but this is poorly constrained.

METAMORPHISM IN THE RECONSTRUCTED OROGENIC BELT

Relatively uniform P-T conditions of 500–550°C and 3.5–4.5 kbar (Grambling and Williams, 1985; Grambling et al., 1989) are well documented across the Tusas, Picuris, Truchas and Rio Mora uplifts. These pressure differences of 0.5 to 1 kbar represent 2 to 4 km differences in depth and are not significant with respect to the proposed piercing lines. Representative P–T estimates of 540°C, 4.0 kbar for the Tusas, 510°C, 3.8 kbar for the Picuris, 510°C, 3.8 kbar in the Truchas and 550°C, 4.5 kbar in the Rio Mora area illustrate the similar P–T conditions along the southernmost thrust fault (Fig. 3; Karlstrom and Daniel, 1993).

Two different P-T trajectories have been suggested for the Proterozoic rocks in these four uplifts. Earlier studies (Grambling, 1986; Grambling et al., 1989) proposed a counter–clockwise P–T loop around the Al_2SiO_5 triple–point with heating and burial from the kyanite field through the andalusite field into the sillimanite field followed by slow, isobaric cooling back into the kyanite field. However, this P-T path does not account for the occurrence of sillimanite inclusions within andalusite and other reaction textures documented in the Truchas and Picuris mountains (Daniel, 1992). An alternate clockwise path based upon work by Grambling (1986), Daniel et al., (1991; 1992), Daniel (1992), Bauer (1993) and Williams and Daniel (1994) is characterized by heating and compression through the kyanite field into the sillimanite stability field followed by an estimated 1 to 2 kbar of decompression towards the andalusite stability field (Fig. 4). The transition from sillimanite to andalusite occurs close to peak metamorphic temperatures, suggesting that decompression directly followed (or possibly, was synchronous with) late-stage shortening.

The slightly different crustal levels represented by the Picuris, Truchas and Rio Mora uplifts preserve a series of nested P-T loops (Fig. 4). Rocks in the Picuris uplift experienced a shallower and cooler P-T loop whereas rocks in the Rio Mora area preserve a deeper and hotter P-T loop. The clockwise P-T path and ~1 kbar of decompression is also consistent with metamorphic data from the southern Tusas uplift. These clockwise P-T loops are interpreted to record crustal thickening and heating at midcrustal depths during the Mazatzal orogeny, followed by 1–2 kbar of decompression possibly representing the extensional collapse of this overthickened crust. This interpretation is consistent with observations (Williams, 1991a; Bauer, 1993) from ductile thrust faults that show north–vergent thrusting (crustal thickening) overprinted by south–vergent extension (decompression). The lack of cooling ages between ~1600 Ma and ~1450 Ma (Bauer and Pollock, 1993) suggests that after decompression, these rocks continued to reside in the middle crust for ~ 200 Ma when the ~ 1450 Ma granites were emplaced at pressures of 3 to 4 kbar.

Perhaps most important to the reconstruction is the fact that metamorphic isograds crosscut the major deformational features in each of these uplifts, indicating that metamorphism outlasted or postdates the major thrusting. This was first documented by Grambling (1981) in the Truchas Peaks area, where the great amount of topographic relief allowed the Al_2SiO_5 isograds to be mapped in three dimensions, and is well documented in the Rio Mora area (Grambling et al., 1989), where the subhorizontal kyanite–sillimanite isograd cuts across thrusts and over-

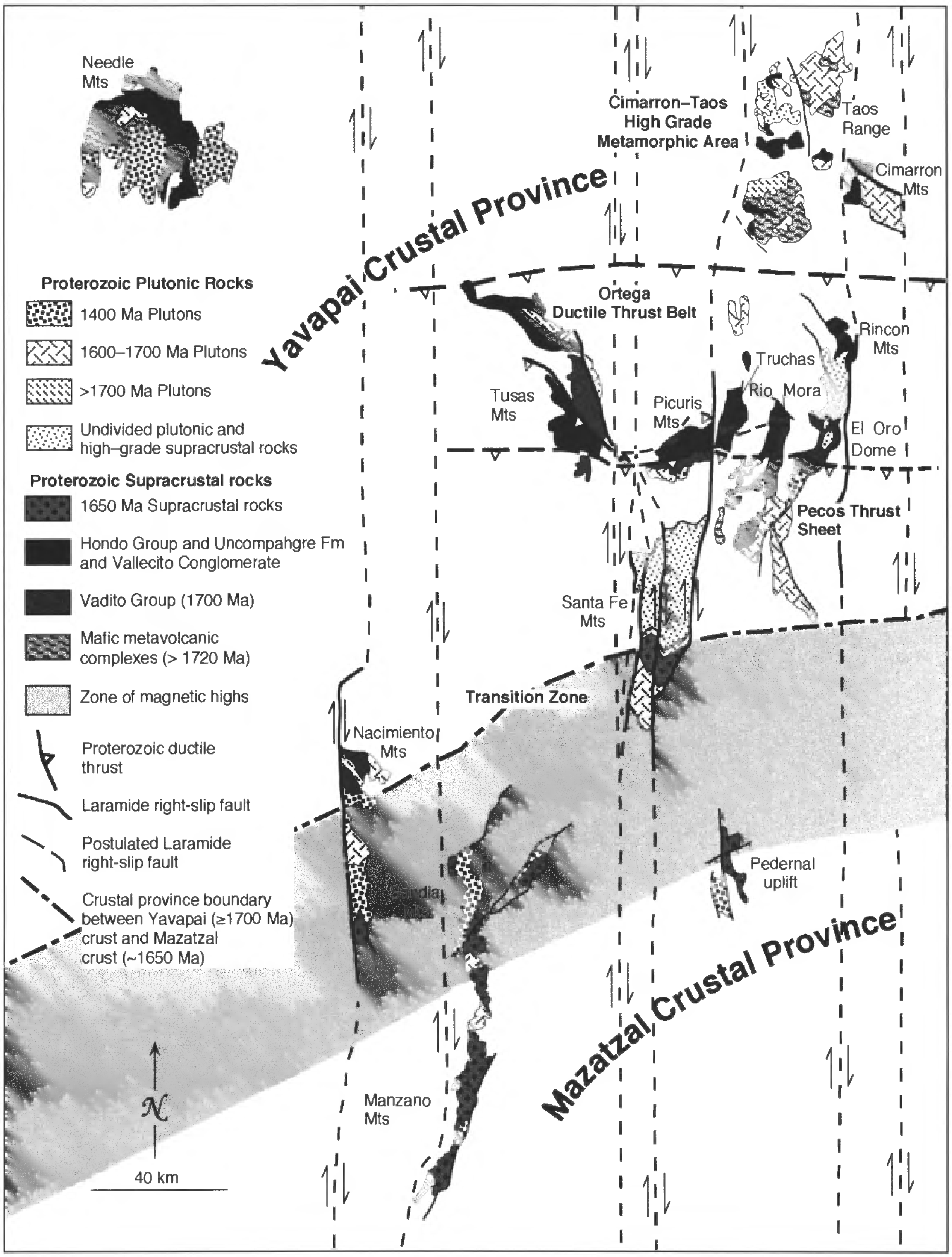

FIGURE 2. Post–1400 Ma, pre–Laramide realignment of Proterozoic rocks in north–central New Mexico and proposed crustal boundary separating ≥1700 Ma rocks from ~1650 Ma supracrustal rocks. The Cimarron–Taos high-grade metamorphic belt is interpreted to represent the deepest and lowest structural level in New Mexico. The Ortega fold and thrust belt represents the deformed Yavapai province foreland caused by the accretion of the Mazatzal crustal province. The Pecos thrust sheet is the uppermost thrust sheet of this complex, characterized by a high density of ~1650 Ma plutons. The northern Mazatzal crustal province is characterized by several ~1450 Ma plutons. Locally, the thermal effects from these plutons overprint the earlier Mazatzal tectonic history. Gray, dashed lines are representative of the Laramide strike-slip fault system proposed for the eastern margin of the Colorado Plateau.

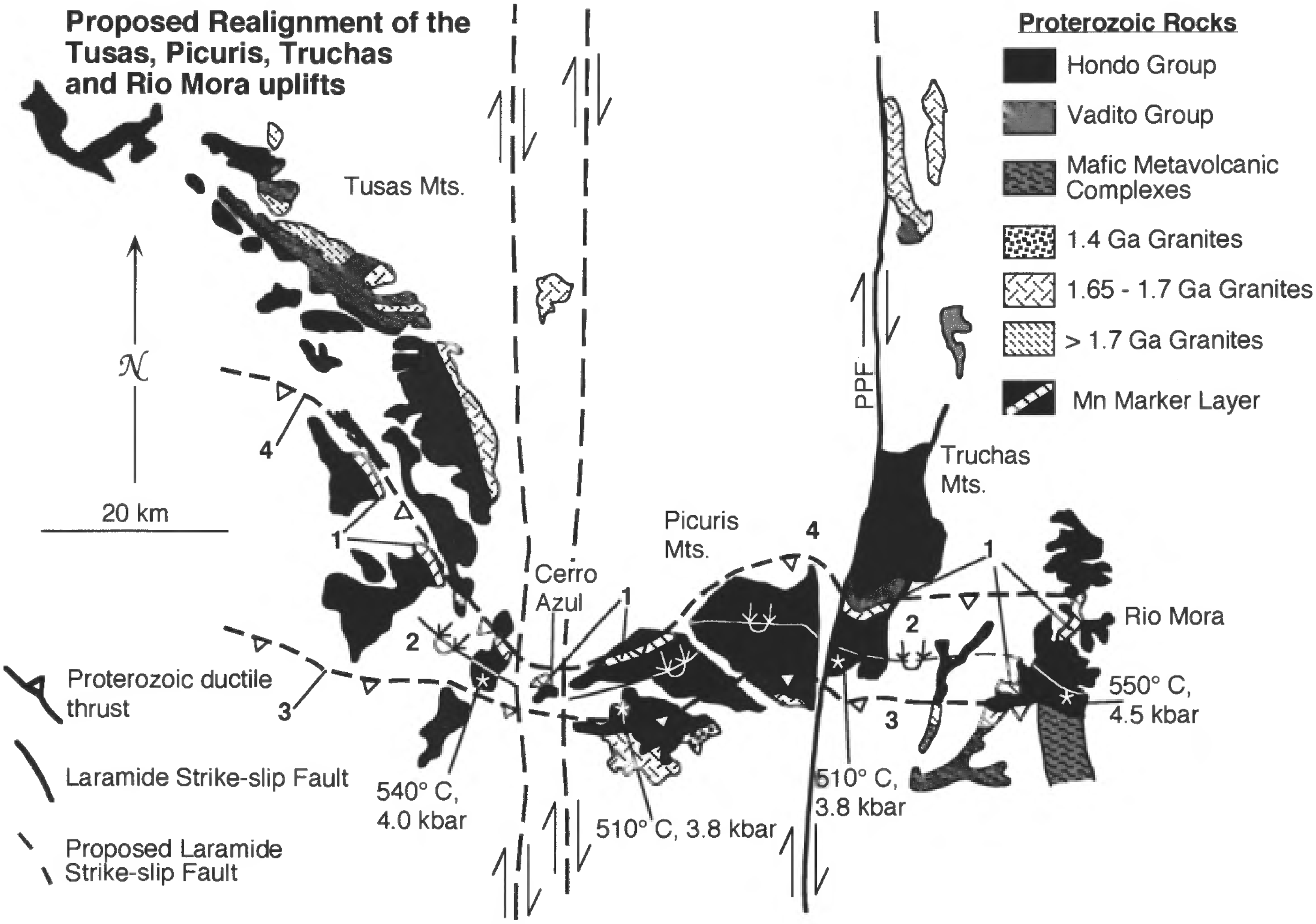

FIGURE 3. Realignment of the Tusas, Picuris, Truchas and Rio Mora uplifts creates an east–trending, Proterozoic fold and thrust belt (modified from Karlstrom and Daniel, 1993). 1, Mn–marker layer; 2, Hondo syncline; 3, Plomo thrust, major thrust bounding the southern limb of the syncline; 4, Pilar thrust bounding the northern limb of the Hondo Syncline. Representative temperature and pressures along the Plomo thrust show similar peak metamorphic temperatures and pressures.

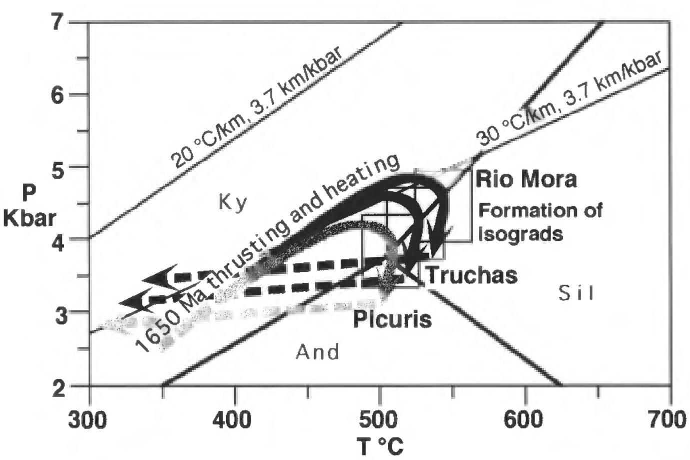

FIGURE 4. Series of nested clockwise P-T loops proposed for the Picuris, Truchas and Rio Mora uplifts (Modified from Daniel, 1992; Bauer, 1993 and Daniel et al., 1991). Heating and compression is interpreted to reflect crustal thickening and pluton emplacement at 1650 Ma. Subsequent decompression probably reflects erosion and minor collapse of the orogen. This is the time of isograd formation. Following decompression the rocks remained at mid–crustal depths and cooled to an ambient geotherm until the emplacement of the ~1400 Ma granites. Peak metamorphic conditions for the Picuris, Truchas and Rio Mora areas are outlined with boxes (Grambling et al., 1989; Al_2SiO_5 triple point from Holdaway and Mukhopadhyay, 1993).

turned folds of the Vadito and Hondo Groups. These relationships are not as well documented in the Picuris and Tusas uplifts due to the smaller amount of topographic relief, but again, isograds in these two areas do appear to crosscut major structures. The geometry of the isograds represents the thermal structure of the midcrust following crustal thickening and heating, and was "locked in" sometime during decompression of the rocks. The Al_2SiO_5 isograd geometry with andalusite in the south and kyanite+sillimanite to the north, indicates a slightly higher thermal gradient to the south (Grambling, 1981). These metamorphic data indicate that each uplift was at approximately the same crustal level (15 ± 3 km) following the regional deformation and that the present erosional level in these uplifts is coincident with a nearly horizontal, 4 kbar isobaric surface. The timing and cause of this metamorphism remains controversial but available geochronologic data strongly suggests these piercing lines were established by ~1400 Ma and probably as early as ~1650 Ma.

CRUSTAL AND DEFORMATIONAL PROVINCES

Karlstrom and Daniel (1993) placed rocks that are 1700 Ma or older, such as the mafic metavolcanic basement complexes and overlying supracrustal cover rocks (Vadito and Hondo Groups), into the Yavapai (1700 Ma) *crustal* province. Younger (1670–1640 Ma) rhyolite–dominated metavolcanic and metasedimentary rocks in the Santa Fe and Manzano mountains are placed into the Mazatzal (~1650 Ma) *crustal* province. This division is somewhat different than the approach of Condie (1992), who grouped the Vadito and Hondo groups and the ~1650 Ma supracrustal sequences into the Manzano overlap sequence. The term "overlap se-

quence" seems appropriate for the Vadito and Hondo Groups, which are interpreted to have been deposited on a continental margin of older, volcanogenic rock. However, the term "Manzano" probably is not desirable, as the Vadito and Hondo groups appear to be some 50 Ma older than supracrustal rocks in the Manzano Mountains (Bowring et al., 1983; Bauer and Pollock, 1993). Karlstrom and Daniel (1993) placed the Yavapai—Mazatzal crustal province boundary south of the reconstructed fold and thrust belt between the southernmost occurrence of 1700 Ma rock and the northernmost occurrence of known 1650 Ma supracrustal rock (Fig. 2). The nature of this transition is not well understood but several of the important features of this zone are discussed in the following section.

The older volcanogenic basement in Colorado (Reed et al., 1987; 1993; Gibson and Simpson, 1988) and Arizona (Karlstrom and Bowring, 1988; 1993) was deformed between 1740 and 1700 Ma, prior to (and possibly during) deposition of the overlying 1700 Ma supracrustal rocks. This early deformation probably is present in the mafic metavolcanic "basement" of New Mexico but is not yet well documented. The regional north-vergent recumbent folds and ductile thrusts are interpreted to represent the deformation of the Yavapai province foreland by the collision of volcanogenic arcs and perhaps continental lithosphere of the Mazatzal crustal province. This deformation extends far inboard of the Yavapai–Mazatzal *crustal* boundary into northern New Mexico and southern Colorado, where it overprints the earlier Yavapai deformation. Therefore, as the Proterozoic rocks in New Mexico record a regional deformation between 1650 and 1600 Ma (Bauer and Williams, 1994; Bauer et al. 1993; Bauer, 1993) they are assigned to the Mazatzal *orogenic* province. It is recognized that in this orogenic belt, as in most, there are areas that have been affected by multiple deformations: pre-1700 Ma, 1650 Ma, and 1450 Ma.

STRUCTURAL, METAMORPHIC AND PLUTONIC BELTS

In addition to the proposed crustal and orogenic province assignments, several distinct structural, metamorphic and plutonic belts are recognized (Fig. 2). From north to south, these belts are informally called (1) the Cimarron–Taos high-grade metamorphic area, (2) the Ortega fold and thrust belt, and (3) the Yavapai–Mazatzal transition zone. The outstanding structural, metamorphic and/or plutonic characteristics that distinguish these areas are summarized below.

Cimarron—Taos high grade metamorphic area

The Cimarron–Taos high–grade metamorphic area consists of old (Yavapai crustal province) volcanogenic basement, younger supracrustal cover rocks and abundant 1650 to 1700 Ma plutons. Metamorphic grade is variable in these two uplifts, ranging from greenschist to upper amphibolite–lower granulite facies (Grambling et al., 1989; Grambling and Dallmeyer, 1993). However, some of the highest pressures and temperatures found in New Mexico make these rocks unique. Relatively high pressures of 6 to 8 kbar were reported by Grambling et al. (1989), Grambling and Dallmeyer (1993) and Karlstrom et al. (1994). These data suggest that much of the Cimarron uplift and northern Taos Range were buried to a deeper crustal level than rocks of the Ortega fold-and-thrust belt to the south. The high temperatures documented in the northern Taos Range (Grambling et al., 1989; Pedrick, unpubl. data) and Cimarron Mountains (Grambling and Dallmeyer, 1993) are likely due to heat from 1650 to 1700 Ma granites that envelop the supracrustal rocks. These rocks may record the locus of crustal thickening during the Mazatzal orogeny.

Ortega ductile thrust belt

The realignment of the Tusas, Picuris, Truchas, Rio Mora and Rincon–El Oro dome areas creates a zone of folds and thrusts that we call the Ortega ductile thrust belt. Structures in this belt consist of syncline–anticline pairs separated by steeply–dipping shear zones (Williams, 1991a). Relatively uniform P-T conditions and clockwise P–T paths characterize a large portion of this belt (Grambling et al., 1989). An interesting characteristic of this belt is that very few 1700 to 1450 Ma plutons intrude the Hondo and Vadito rocks. Plutons are present to the north and south of the bounding thrusts of the Hondo Group and at the eastern end of this belt in the Rincon–El Oro dome area. Rocks in the Rincon–El Oro dome may represent the lowest structural level of this fold and thrust belt. A large number of plutons intrude the rocks in this area (Baltz and O'Neill, 1980a, b; Moench et al., 1988; O'Neill, 1990; Grambling, unpubl. mapping) and may be responsible for locally higher metamorphic temperatures. The geometry and deformational style in this belt is interpreted to be equivalent to the deeper levels of a foreland thrust belt and to represent the deformation of the Yavapai crustal province foreland during the Mazatzal orogeny.

Yavapai–Mazatzal transition zone

The Yavapai–Mazatzal crustal province transition zone includes Yavapai-age rocks south of the Ortega fold-and-thrust belt and Mazatzal age supracrustal rocks in the Santa Fe, Sandia, Manzano, Pedernal uplifts and possibly, the Nacimiento uplift. This transition zone is characterized by the Pecos thrust sheet and a large number of ~1650 Ma and ~1450 Ma plutons. The Pecos thrust sheet represents the southernmost exposure of known, pre–1700 Ma volcanogenic basement and is thrust over the Ortega fold-and-thrust belt. We suggest that this is the uppermost thrust sheet to the Ortega fold-and-thrust belt as no exposures of the Hondo Group are known to the south. The Santa Fe Mountains and lower Pecos river valley are characterized by a large number of ~1650 Ma granites and a few ~1450 Ma plutons. In the central Santa Fe Mountains these plutons are responsible for the synkinematic, partial melting of metasediments (Metcalf, 1990). Thermobarometry shows metamorphic P-T conditions of 650–730 °C, 5.0–5.5 kbar for the central Santa Fe Range (Metcalf, 1990). The thrusting of the ~1650 Ma plutons in the Pecos sheet over the Ortega thrust belt may have contributed to the regional metamorphism in the Ortega thrust belt.

The majority of ~1450 Ma plutons in New Mexico occur south of the Ortega fold-and-thrust belt. Only a few plutons of this age (the Penasco and Macho Creek granites; Bauer and Pollack, 1993) are documented in the Pecos thrust sheet (southern Yavapai crustal province); the majority appear to intrude into the northern Mazatzal crustal province. The dominant feature of the northern Mazatzal crustal province is an east-trending belt of ~1450 Ma granites defined by the Joaquin granite and Nacimiento quartz monzonite in the Nacimiento uplift, the Sandia granite exposed in the Sandia Mountains, and an unnamed granite in the Pedernal hills. This belt may also include unnamed ~1450 Ma plutons from the Zuni uplift (Bauer and Pollock, 1993). Mineral assemblages and geobarometry around the Sandia granite (Andronicos et al., 1993) and the ~1440 Ma Priest pluton (Thompson et al., in prep.) in the southern Manzano Mountains suggest that these plutons were emplaced at pressures of 3–4 kbar. In the contact aureoles of the Sandia and Priest granites, assemblages of sillimanite + K–feldspar or andalusite + sillimanite + K–feldspar and garnet–biotite thermobarometry indicate temperatures near 650–700°C. These plutons played an important role in locally overprinting the earlier ~1650 Ma metamorphism and thermally softening the middle crust to allow for the reactivation of earlier (~1650 Ma) fabrics and the local formation of new fabrics (Nyman et al., 1994).

METAMORPHISM IN THE ORTEGA THRUST BELT

The geometry of the structural, metamorphic and plutonic belts discussed above may offer new insight in understanding the nature of the regional metamorphism in the Ortega fold-and-thrust belt. The regional metamorphism in north–central New Mexico is difficult to explain and requires a model whereby rocks are heated to temperatures of 500–550 °C at a depth of 12–15 km (well in excess of standard geothermal gradients) across a large area. Grambling et al. (1989) proposed a regional, extensional detachment fault that juxtaposed an upper plate of medium–grade metamorphic rocks against a lower plate of high–grade gneisses at ~1400 Ma. Heat conducted from the high–grade lower plate to the upper plate resulted in the peak " Al_2SiO_5 triple–point" metamorphism. However, recent work (Karlstrom et al., 1994) challenges the existence of such a regional detachment fault in New Mexico. We propose an alternate model to explain the regional metamorphism in the Ortega fold-and-thrust belt. The large number of ~1650 plutons in the structurally

lower Cimarron–Taos high–grade area and the Rincon–El Oro dome area and in the overriding Pecos thrust sheet suggests that the Ortega thrust belt was "sandwiched" between two layers with a high proportion of ~1650 Ma plutons. We suggest that the heat from these plutons was responsible for the regional "triple–point" metamorphism found in the Ortega thrust-and-fold belt. This model is consistent with the Al_2SiO_5 isograd geometry that shows an increasing thermal gradient to the south. The higher temperatures and pressures documented in the central Santa Fe Range (Metcalf, 1990) are also consistent with thrust emplacement of these rocks over the Ortega thrust belt.

SUMMARY

The realignment of Proterozoic rocks presented in Figures 2 and 3 provides the basis for a new working model of the distribution of crustal and deformational provinces in New Mexico. The two–fold division of rocks into the Yavapai and Mazatzal crustal provinces is an alternate view of the distribution of Proterozoic rocks in New Mexico compared to the terrane analyses presented by Grambling et al. (1988) and Condie (1992). In addition, several structural, metamorphic and plutonic belts are recognized and their geometry and characteristics provide clues to the overall tectonic evolution of New Mexico. The Cimarron–Taos high–grade metamorphic area appears to preserve a deeper structural level than the Ortega ductile thrust belt to the south. Heat associated with 1650 to 1670 Ma plutons is responsible for the high temperatures found in the northern Taos Range and the Cimarron Mountains. The Ortega ductile thrust belt is interpreted as a crustal–scale duplex structure with few 1650 to 1700 Ma plutons. The Yavapai–Mazatzal crustal province transition zone is dominated by ~1650 Ma plutons along the southern margin of the Yavapai crustal province and by ~1450 Ma plutons along the northern margin of the Mazatzal province. The Pecos thrust sheet is interpreted as the overriding thrust to the Ortega ductile thrust belt. This thrust sheet carried syntectonic ~1650 Ma granites over the Ortega ductile thrust belt, helping to heat the rocks to relatively high temperatures (~520°C) at a moderate to shallow crustal level. This syn–thrusting, pluton-enhanced, regional metamorphism (Williams, 1991b) provides an alternate model to the regional, extensional detachment model of Grambling et al. (1989) and Grambling and Dallmeyer (1993).

ACKNOWLEDGMENTS

This work is dedicated to the memory of Dr. Jeff Grambling, advisor, colleague and most importantly friend. We thank Matt Nyman and Paul Bauer for constructive reviews and comments.

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